A Simple Laser Microphone for Classroom Demonstration

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Communication through the modulation of electromagnetic radiation has become a foundational technique in modern technology. In this paper we discuss a modern day method of eavesdropping based upon the modulation of laser light reflected from a window pane. A simple and affordable classroom demonstration of a "laser microphone" is described.

The idea of communicating by use of modulated light is an idea that has been around since at least the 1880s. At that time, Alexander Graham Bell devised a system for modulating light from the Sun and receiving this modulated light some distance away where it could be converted into audible sound. His system used a mouthpiece that concentrated sound onto a reflecting diaphragm. Sunlight that was aimed at the diaphragm was reflected and received by a transparent chamber filled with gas. Bell found that he could detect audible sound from the chamber when the light that was reflected onto it was modulated by vibrations in the reflecting diaphragm. What Bell had discovered is now known as the photoacoustic effect.

The phenomenon is now well-understood. The modulation of the light that is received by the absorbing substance produces a modulation in temperature in the substance through a photothermal effect. Since the gas is restricted in volume by its container, the temperature modulation in turn produces pressure modulation and thus an acoustic signal.[1]

Later versions of the photophone used crystalline selenium cells instead of the gas-filled chamber. Selenium's electrical resistance varies with illumination.[2] A sensitive earphone connected to the selenium cells could clearly reproduce the voice from the mouthpiece. Bell called his device a photophone.

A modern day electronic version has been described by Forrest M. Mims in a Radio Shack publication.[3] Bell, of course, is famous for his invention of the telephone, but in a letter he wrote to his father on Feb. 26, 1880, to announce the successful test of the pho-

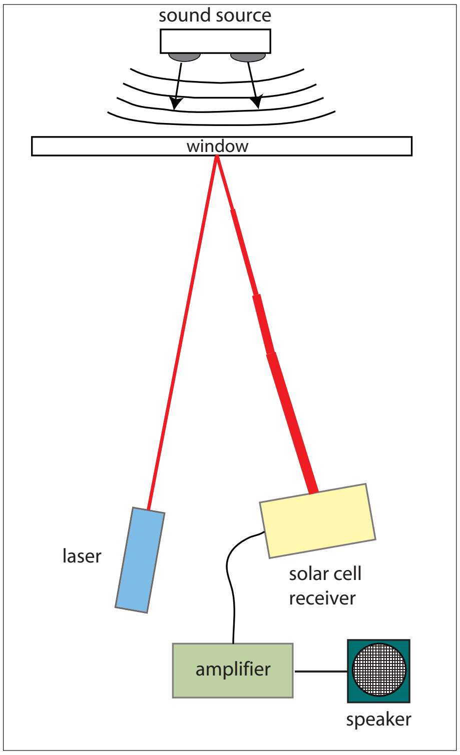

Fig. 1. A schematic of the laser microphone system.

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tophone, it is clear that he considered his photophone an even greater invention than the telephone. In this letter he states, "In general science, discoveries will be made by the Photophone that are undreamed of just now." He further writes, "I have applications enough in my mind to have set me down as a madman...."[4] Bell was correct about the significance of his invention. His photophone is commonly recognized as the progenitor of many modern optical communication devices.

Of interest here is the fact that the photophone concept has been utilized by various law enforcement and intelligence agencies over the years—organizations such as the FBI, CIA, and KGB. This concept made it possible to listen to conversations inside of a room that had a window without ever getting near the room in question.[5,6] Laser surveillance units similar in design to the one we describe here are even commercially available now on the Internet.[7]

The laser microphone system described here (see Fig. 1), which is a modern variation of Bell's photophone, produces results that mimic those created by professional systems used by the aforementioned spy agencies. However, this system will produce decent fidelity for a fraction of the cost of systems used in government surveillance.

Required Hardware

The demonstration requires the following items:

1) a typical classroom helium-neon laser,
2) a silicon solar cell,
3) an audio amplifier,
4) a speaker (headphones may be substituted),
5) a 100-W portable stereo system (i.e. a "boom box"), and
6) a 2.2-mm thick pane of window glass (roughly 75 cm x 75 cm).

The solar cell can be purchased at your local electronics or science store, and the window glass is commonly available at home improvement centers and hardware stores.

It is worth noting that the two most expensive components, the amplifier and laser, can be replaced by very affordable and easily obtainable models. A small combination audio amplifier and speaker can usually be purchased at your local electronics shop. Look in the science fair section. Also, during early experimentation, a pen-style laser pointer was used successfully in place of the helium-neon laser. However, a quality audio amplifier and more powerful laser can give improved fidelity.

Configuration

We have successfully used a window in our conference center as the reflective diaphragm for this demonstration, but a freestanding piece of window glass is generally better to work with since its position can be easily adjusted. The window glass is set on a table and propped up with a small amount of contact near the top edge of the glass. The support device is not critical. We have successfully used objects as crude as weighted cardboard boxes. The key is for the window glass to be propped so that it is free to vibrate. The radio is then placed behind the window as close as possible without actually touching the window.

The laser is aimed at the window with an angle of incidence of approximately two degrees from the normal. The receiver is placed near the transmitter and is also aimed at an angle of two degrees from the normal to the window. This angle was arbitrarily chosen after experimentation with a wide range of angles. The small angle allows the components to be placed in close proximity to each other and to a power supply.

Obviously, smaller angles of incidence allow the system to be moved further away from the window. We have successfully used this laser microphone with both the transmitter and receiver as far as 25 m away from the window.

It is recommended that all overhead lights be switched off and shades be drawn over all windows except for the object window. This prevents the solar cell from receiving light from these sources, which would in turn be reproduced as unwanted audible noise, most likely in the 60-Hz frequency range. In practice we have obtained satisfactory results by shielding the solar cell by placing it in a covered box with an entry hole cut out of the front, thus allowing some ambient light to be present in the room.

Signals from the solar cell are sent by wire to an amplifier and then to an 8-Ω speaker. If performing the demonstration in a small classroom, using headphones in place of the speaker can be helpful. The headphones allow the sound from the laser mi-

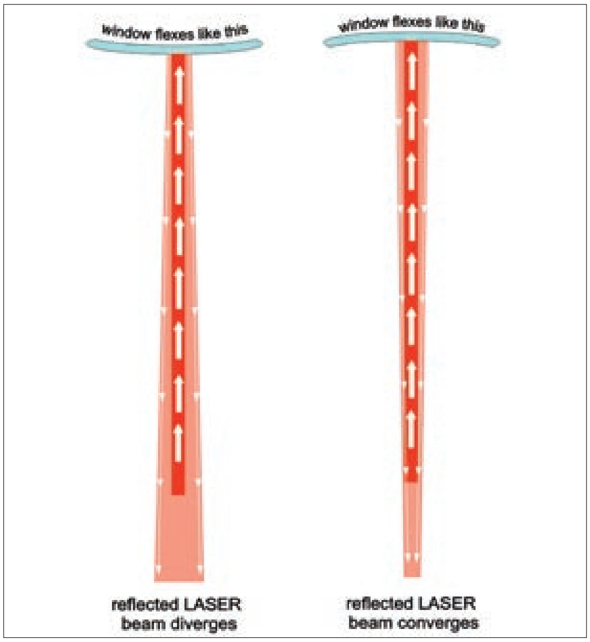

Fig. 2. As the window pane vibrates, its radius of curvature fluctuates. This creates a reflecting surface with a varying focal length. The divergence of the reflected laser beam fluctuates.

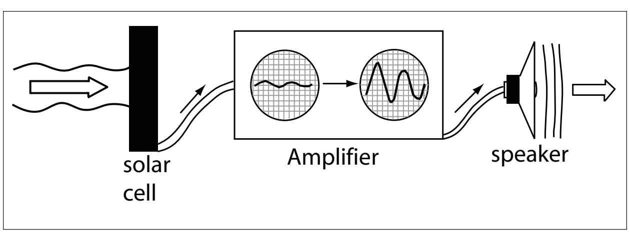

Fig. 3. The fluctuating brightness of the reflected light is converted to a voltage signal by the solar cell. The signal is then amplified and sent to the speaker.

crophone system to be easily distinguished from the sound from the portable stereo system.

How It Works

The radio produces sound on the outside of the window, which causes vibration in the window glass. The vibrations in the glass pane cause the window to flex, changing the center of curvature of the window, thereby causing the focal length of the window to change, albeit very slightly. This creates a varying divergence in the reflected laser beam. This is shown in Fig. 2, although the effect has been greatly exaggerated for clarity. Thus, even small vibrations cause a measurable variation in the energy density of the light reaching the solar cell. The variations in the energy density correspond to the original audio information coming from the radio.

The variation in energy density at the solar cell causes the voltage across the cell to fluctuate. The solar cell receives the audio information carried by the modulated light energy density and transforms it into a fluctuating voltage. This voltage signal carries the original audio information, and it is then sent to an amplifier where it is amplified to a level that can drive the speaker. This process is represented in Fig. 3. The reproduced sound is clearly recognizable as that being produced by the portable stereo system.

One can easily prove that the sound coming from the laser microphone speaker is being carried by the laser beam and is caused by vibrations in the window glass. Interrupting the laser beam with your hand will cause the recognizable sounds coming through the speaker to disappear. Also, tapping lightly on the window with a finger will produce audible sounds through the laser microphone system.

It is worth noting that some solar cells can be overdriven by a reflected laser beam that is too bright, thus causing some of the modulated light signal to be clipped when converted to a voltage. Improved performance can be attained in this case by allowing only the edge of the reflected laser beam to contact the solar cell. Angling the solar cell so that the reflected laser beam contacts the solar cell at a large angle of incidence (i.e., so the laser beam grazes the solar cell) can also improve the fidelity. This geometry allows the slight fluctuations in the diameter of the beam to translate into larger voltage fluctuations.

Final Comments

While tinkering with laser microphone systems for classroom demonstrations is legal, using them for actual surveillance without proper permission is not.

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